Cherenkov and scintillator light readout with SiPM on tiles

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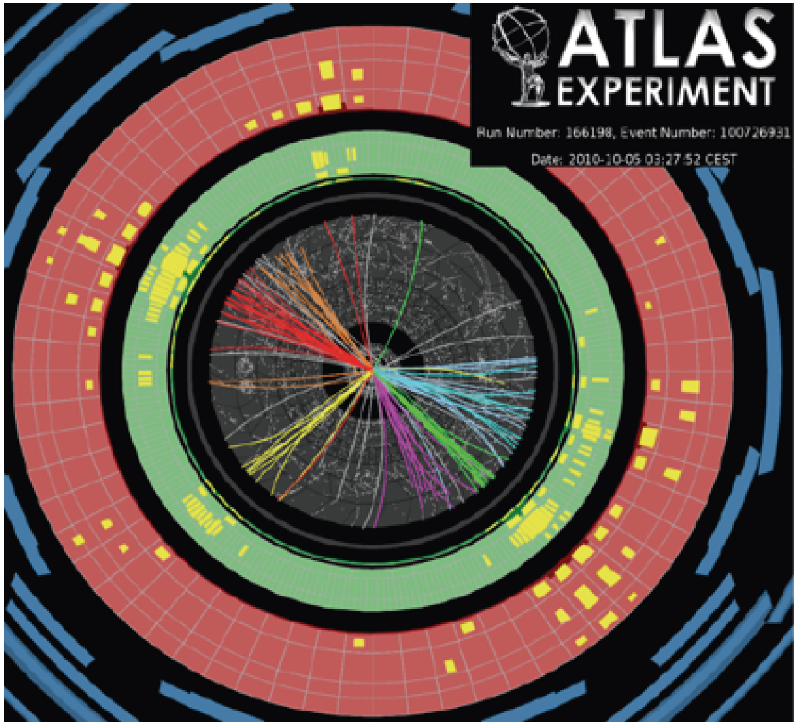
Outline

- Highly granular calorimeters for Particle Flow
- Current designs of tile + SiPM systems for scintillator light r/o

- Motivation for Cherenkov light r/o tiles
- Preliminary tests with Sapphire material

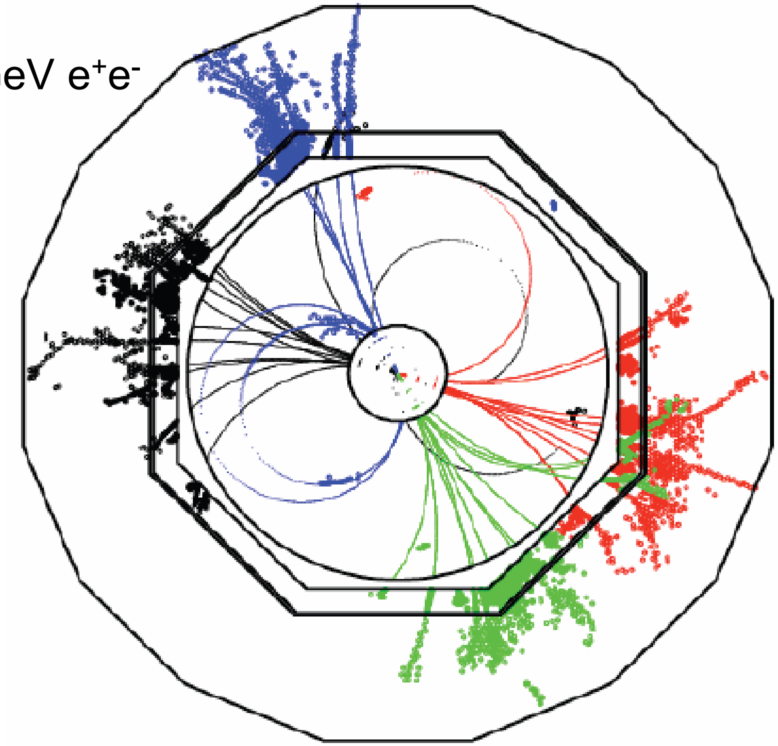
- Conclusions / Outlook

Calorimeters of today and tomorrow



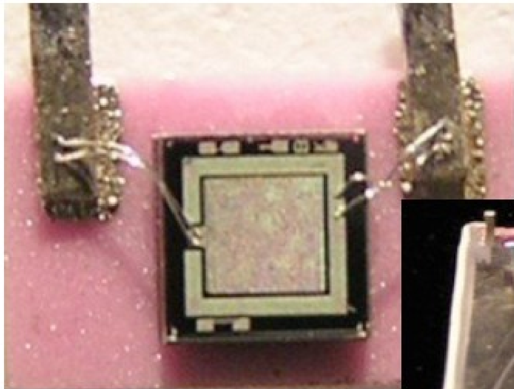
- Tower-wise readout: light from many layers of plastic scintillators is collected in one photon detector (typically PMT)
O(10k) channels for full detectors

ILC:
500 GeV e^+e^-

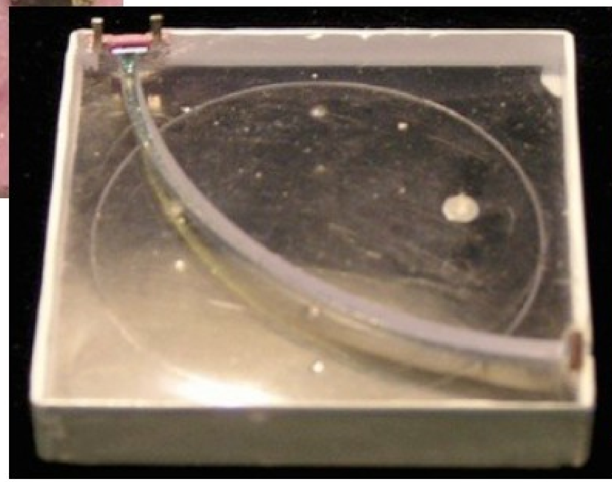


- Extreme granularity to see shower substructure: small detector cells with individual readout for Particle Flow
O(10M) channels for full detectors

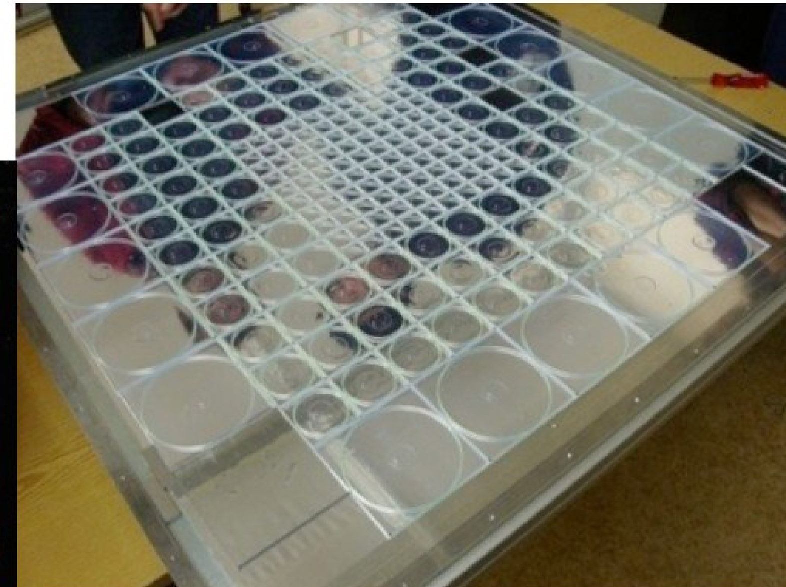
Readout solutions for highly granular calorimeters



SiPM
MEPhI/Pulsar



3 x 3 cm^2 plastic scintillator tile with embedded WLS fiber



Calorimeter layer: 212 tiles, varying size

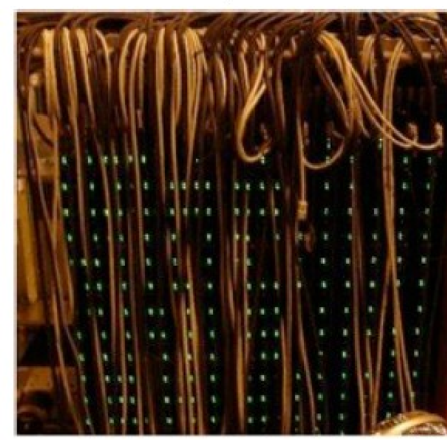
CALICE hadronic calorimeter prototype:

- sandwich structure scintillator tile + SiPM
- WaveLengthShifter fiber needed to match SiPM sensitivity (PDE)

The CALICE collaboration , JINST 5 P05004

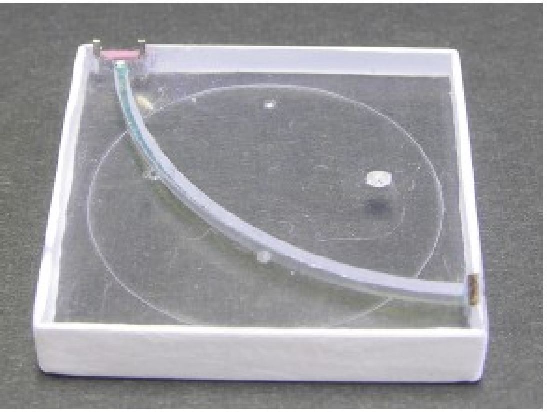
Analog HCAL:
38 layers
7608 channels total

same order as ATLAS

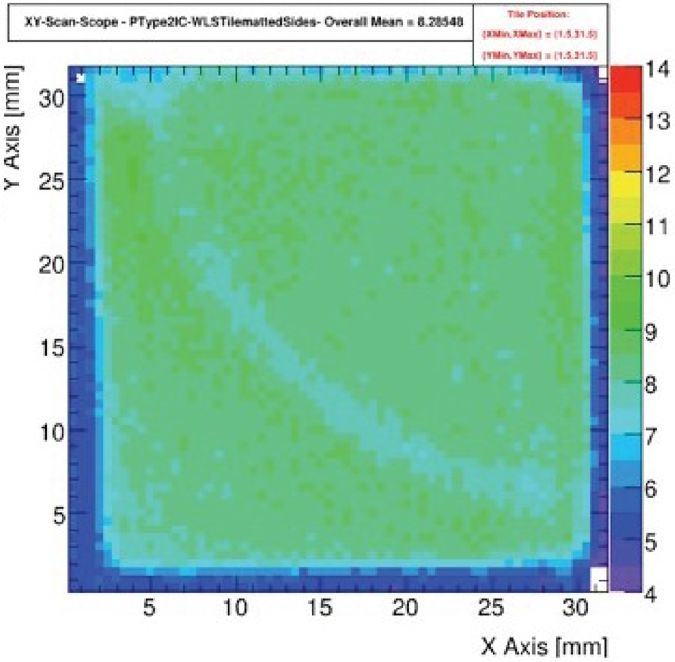


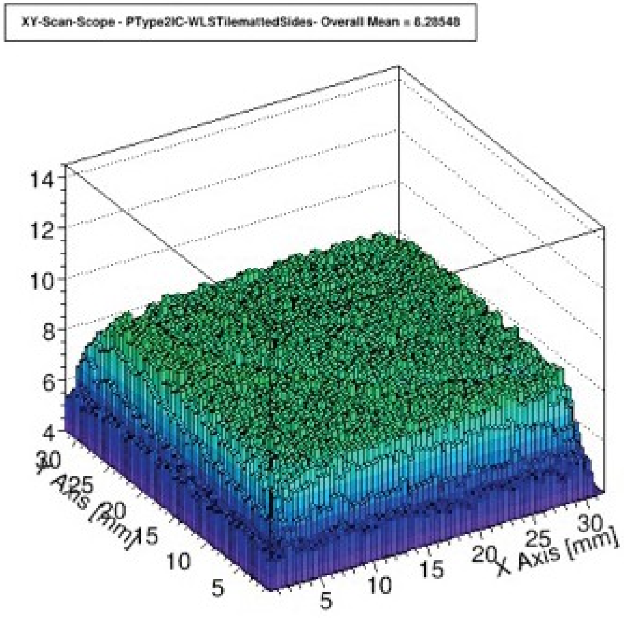
Tile uniformity

- The fiber does not only shift the wavelength - it also collects light and guides it to the SiPM by total internal refection:
  Provides uniform response over the tile surface



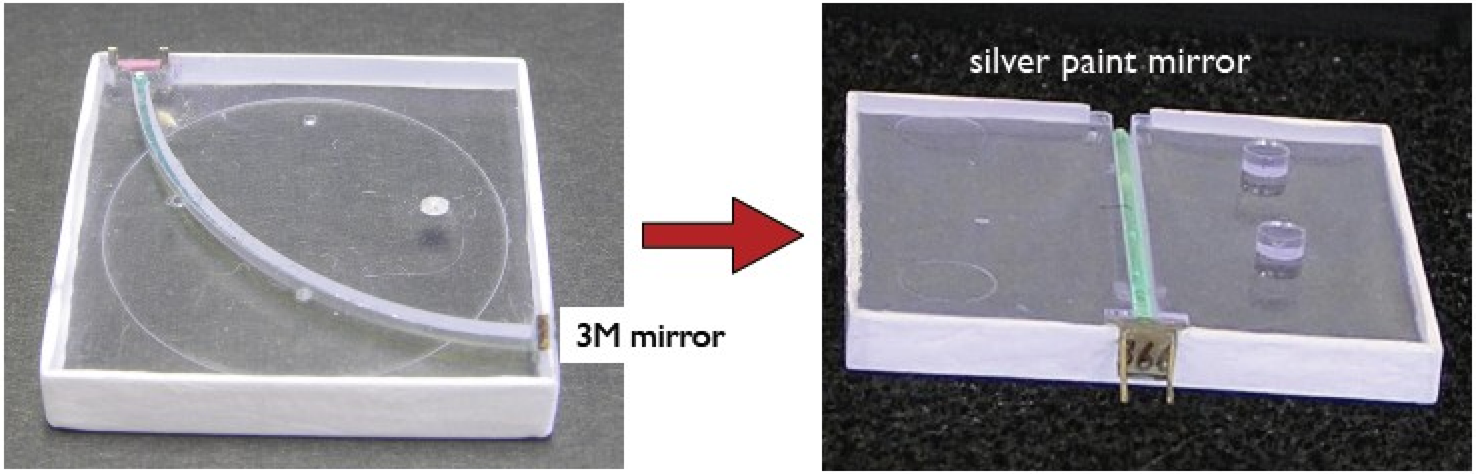
For this test: tile read out with MPPC - sensitivity not well matched to fiber emission





Variation on SiPM + scintillator tiles

- Thinner active layer = significant cost reduction (inside the magnetic coil)
- Straight WLS fiber = simplification in production
- Still sufficient light collected for a Minimum Ionizing Particle (MIP)



5 mm thickness

3 mm thickness

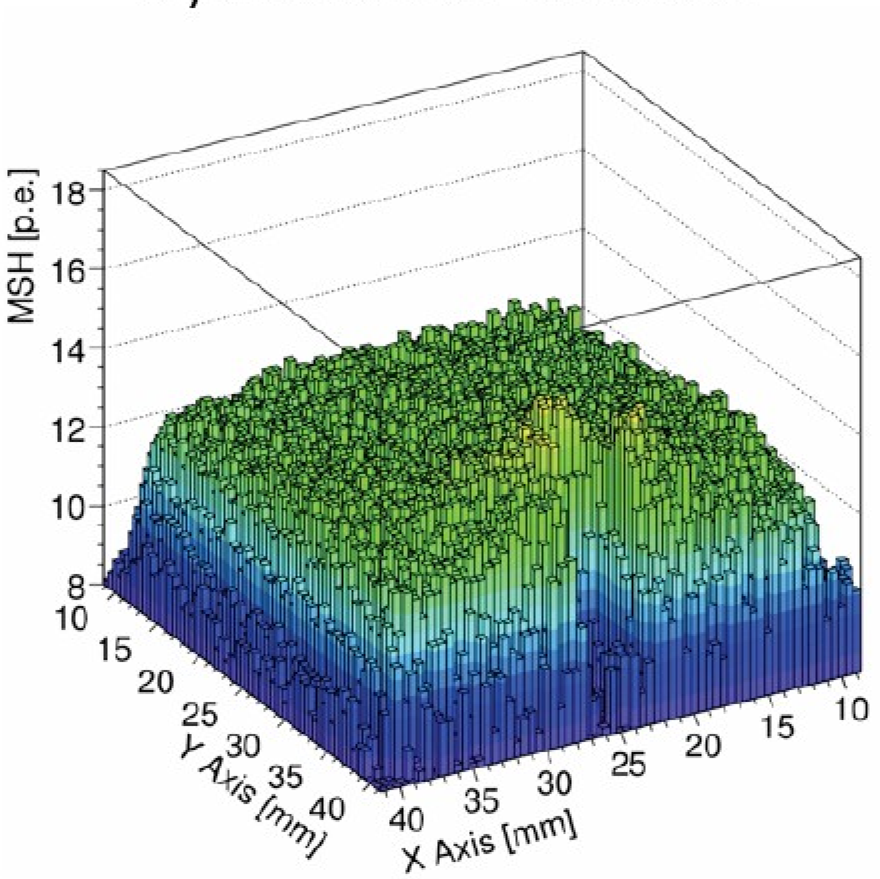
"Lego" alignment pins

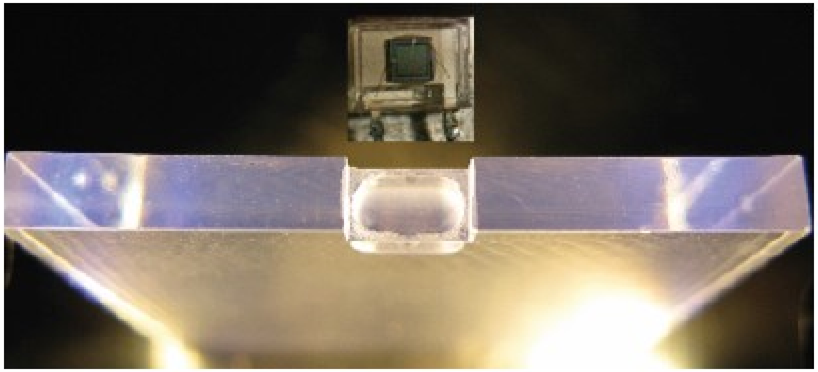
Light Yield = 15 pixels / MIP 12 pixels / MIP

EG et al, EUDET-Report-2010-02

Variation on SiPM + scintillator tiles

- 3 mm thick tiles for 2nd generation
- "Ideal" tile: BC-420 scintillator
  - fully enclosed in 3M reflective foil





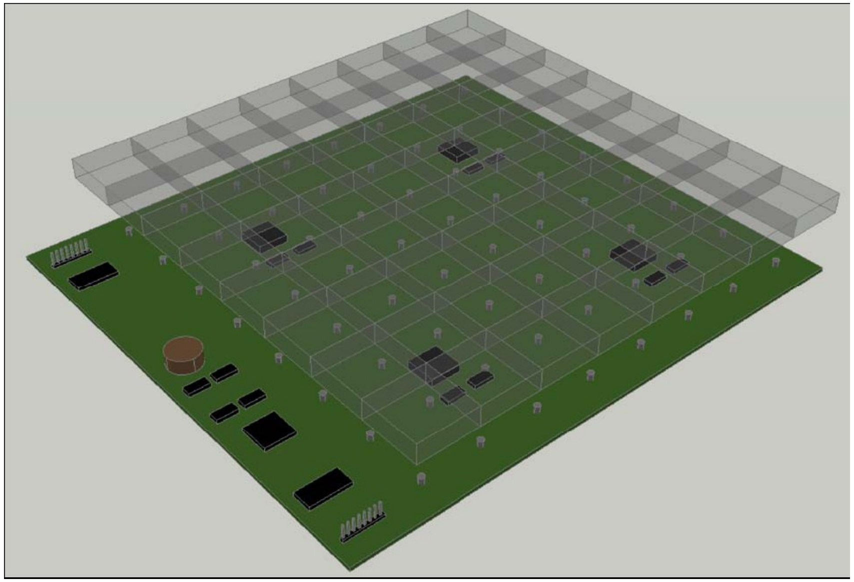
Direct coupling possible using blue sensitive SiPM (Hamamatsu)

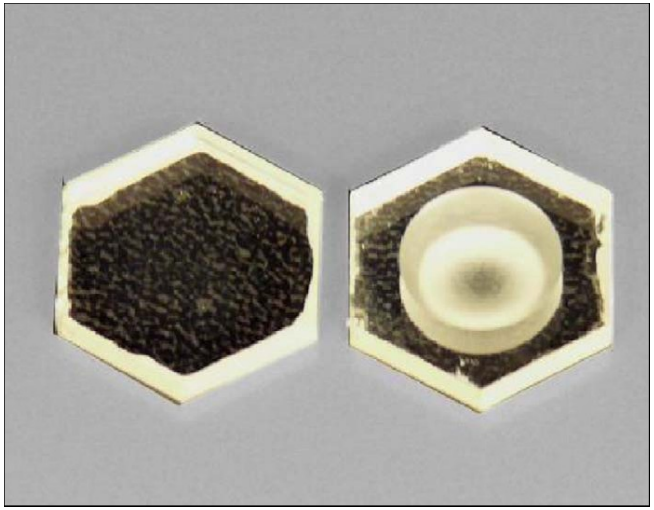
- Excellent uniformity
- High signal amplitude: mean 13 p.e.
- loss of signal at SiPM position

F. Simon et al., NIM A 620, (2010) 196-201

Variation on SiPM + scintillator tiles

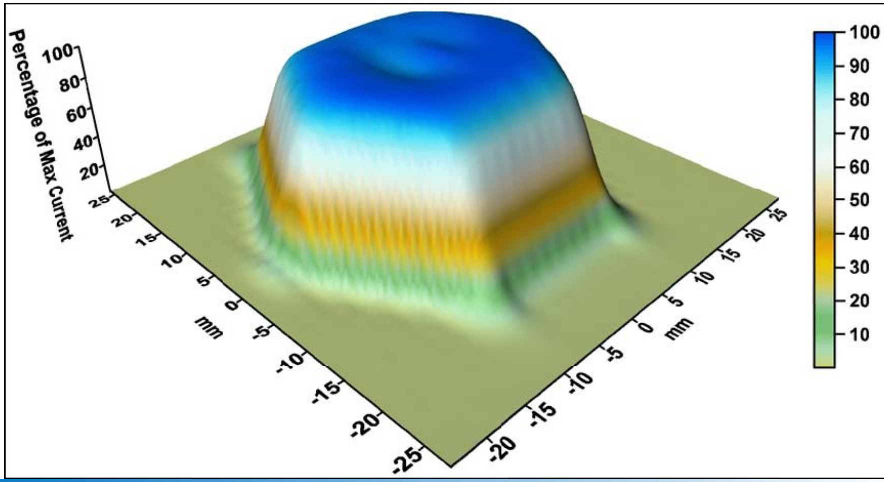
- Direct coupling of SiPM from the bottom of tile
- Requires concave machined scint. for uniformity



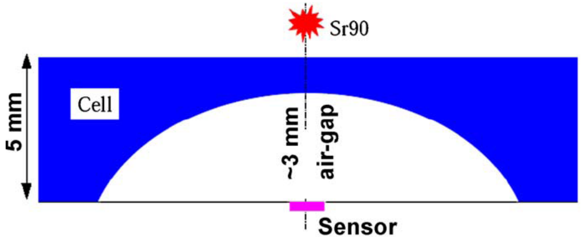


5 mm thickness

Tested with MPPC S10362-11-50C



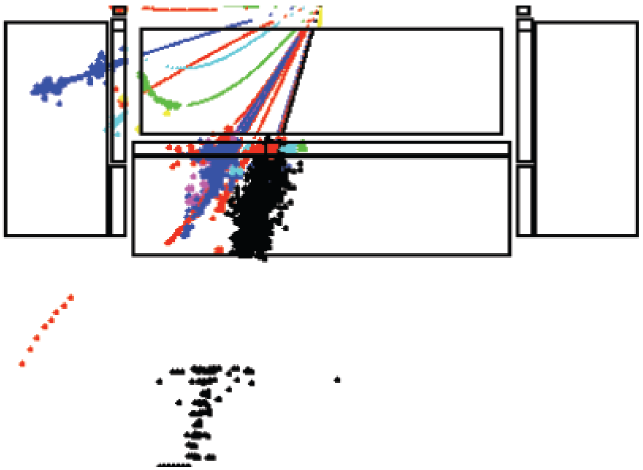
Light Yield =
10 pixels / MIP



G. Blazey et al., NIM A 605 (2009) 277–281

The next challenge for particle flow

Beyond ILC ➔ CLIC a 3 TeV e^+e^- linear collider
Higher gradient: 100 MV/m vs 35MV/m
Higher cms energy: 3 TeV vs 500 GeV

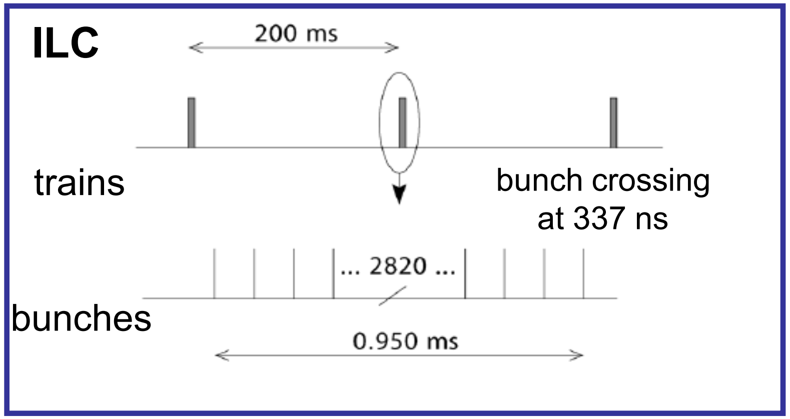


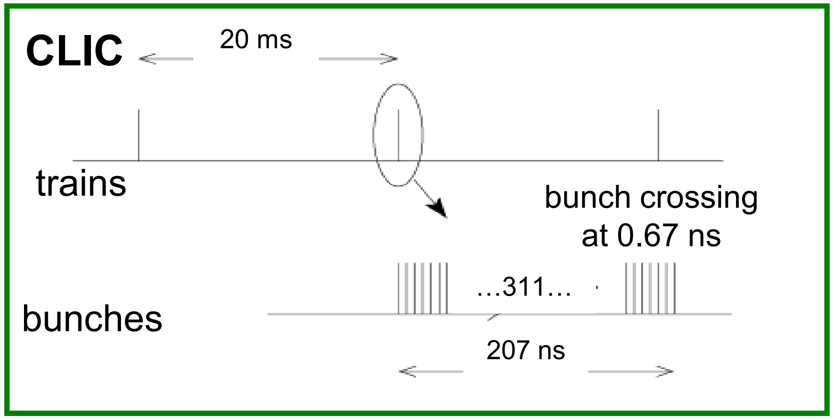
- In principle up to 1.5 TeV jets

➔ PFlow may be worse than calorimeter at this E

- Price to pay: 0.5 ns bunch crossing

➔ Time stamp O(10ns) mandatory



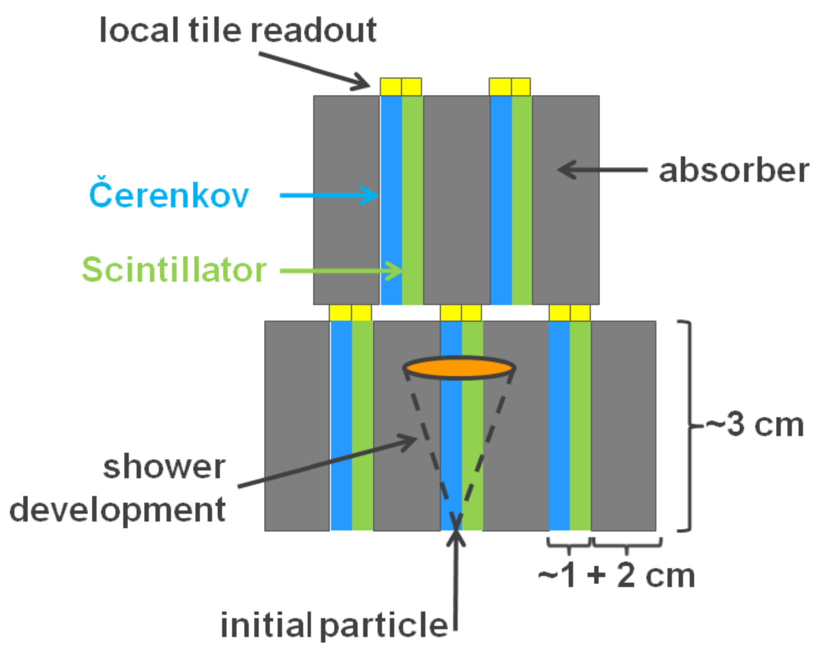


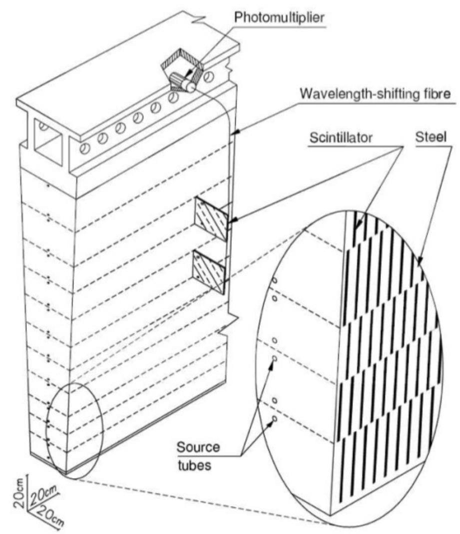
Dual readout with high granularity

- IDEA: Maintain the power of high granularity for Particle Flow but add the measurement of electromagnetic fraction (dual readout) to improve the energy resolution when using calorimeter info only

  + time stamp the shower core with fast readout electronics (<1ns)

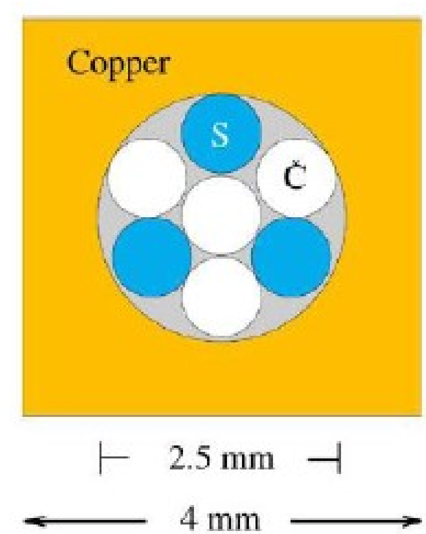
→ Use Cherenkov light emitting tiles in addition to scintillator ones





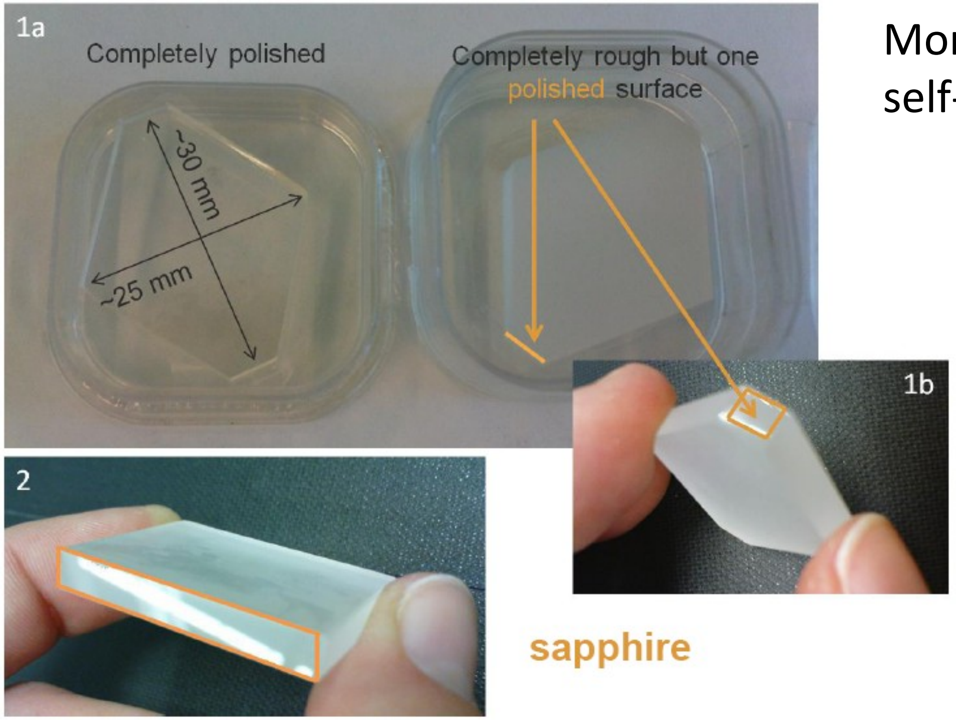
Orientation a-la' ATLAS tilecal

Dual readout a-la' DREAM



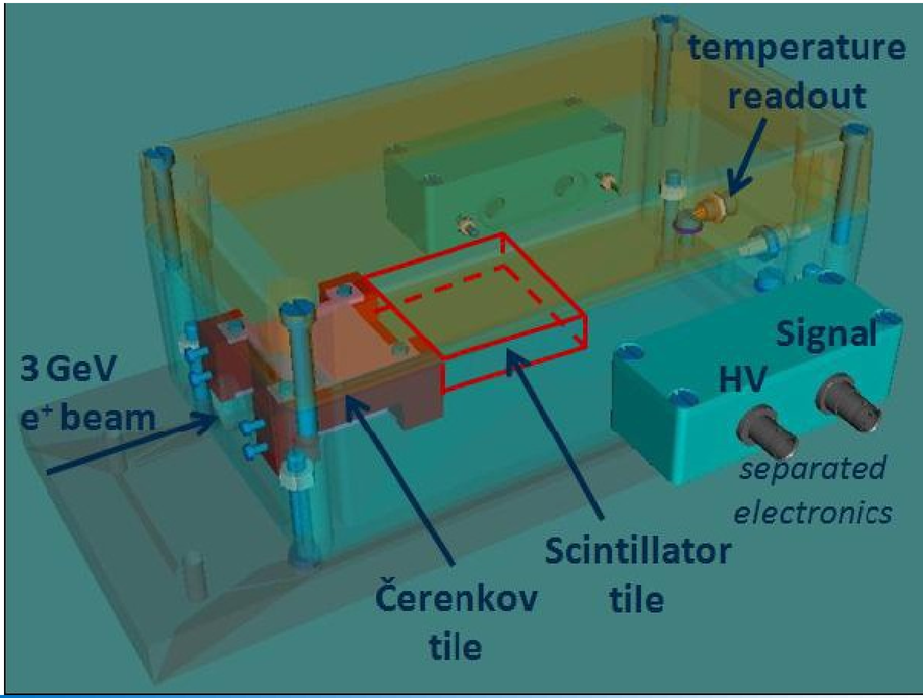
Tested materials

- Sapphire tiles from RSA Le RUBIS (Density: 4 gr/cc, Optical index: 1.76)



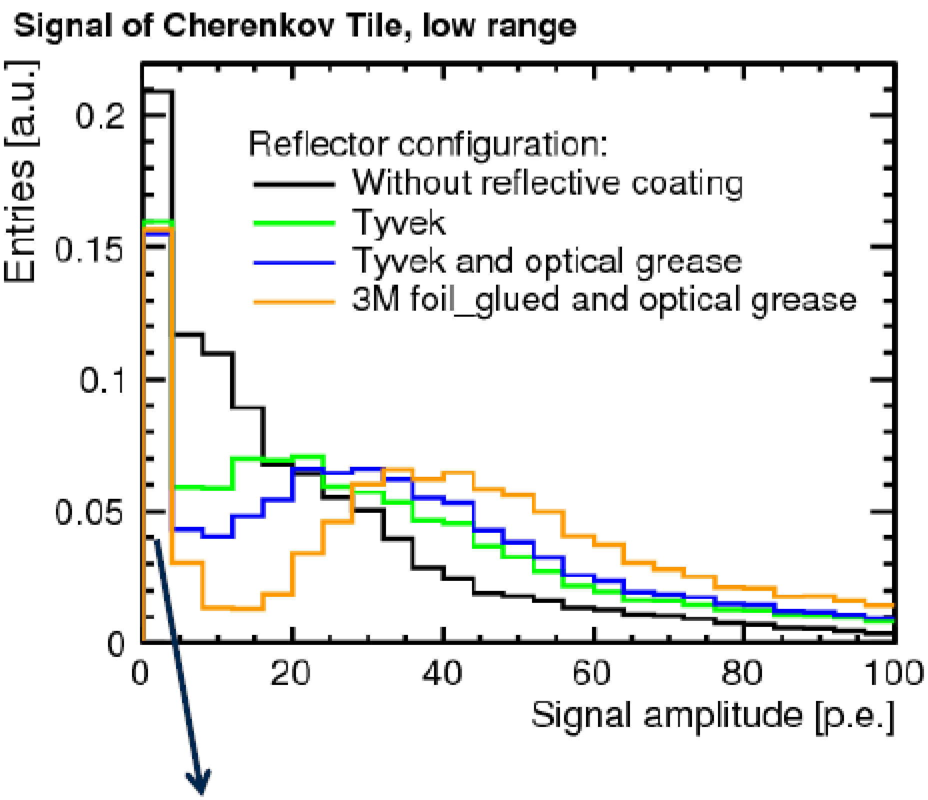
More dense than Quartz but problem with self-absorption (see back-up slides)

Use DESY test beam (e^+ 3 GeV) and tag on MIP like signal in a scintillator tile behind the tile under study

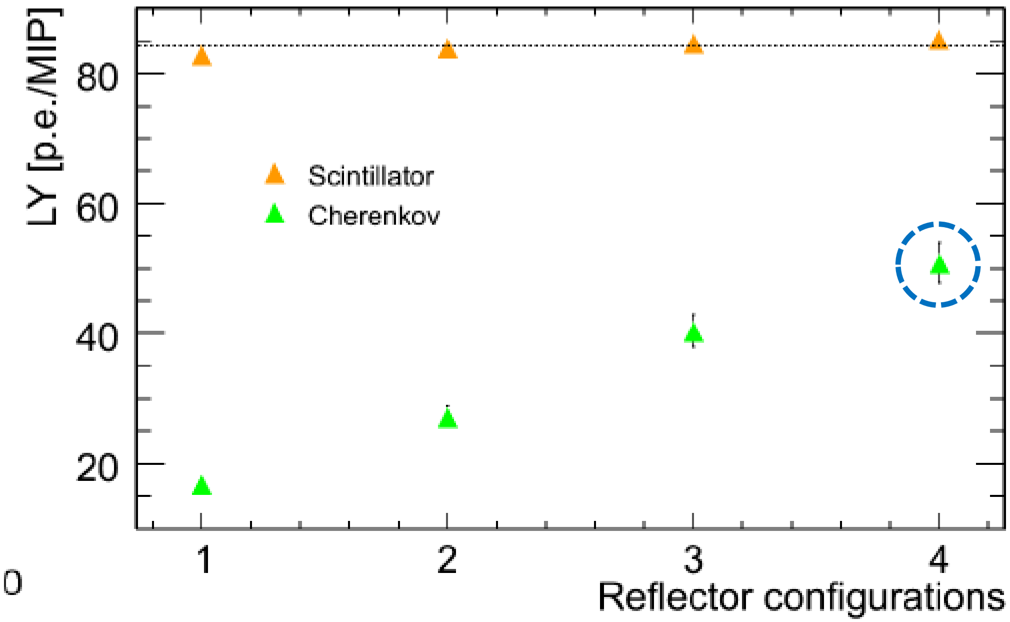


Optimization of wrapping

REFLECTIVE WRAPPING



stable noise level,
small RMS

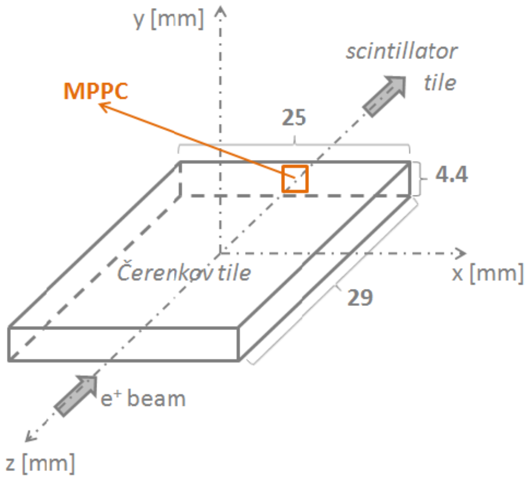


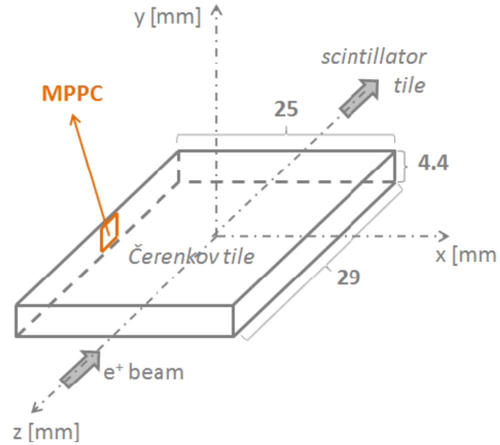
3M foil is used as wrapping of all tiles

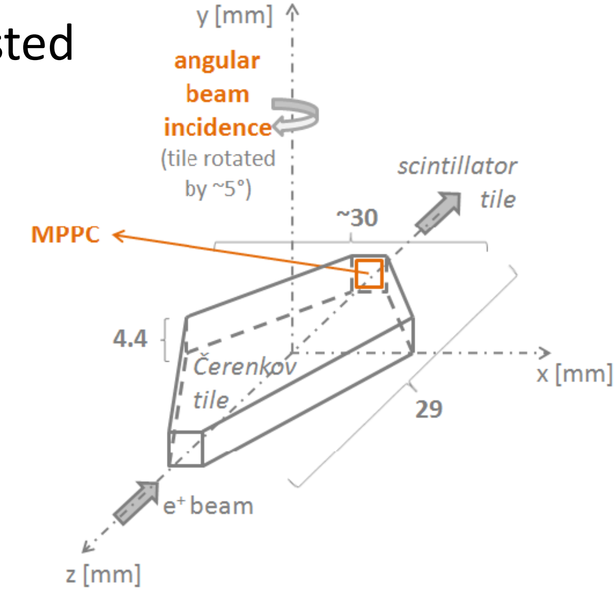
* A portion of light may be of scint. Nature from the 3M foil

Geometry studies

Different tile shapes and photo-detector position tested

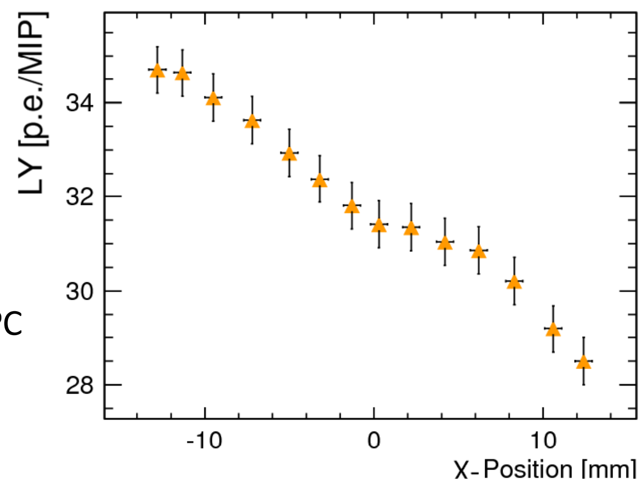






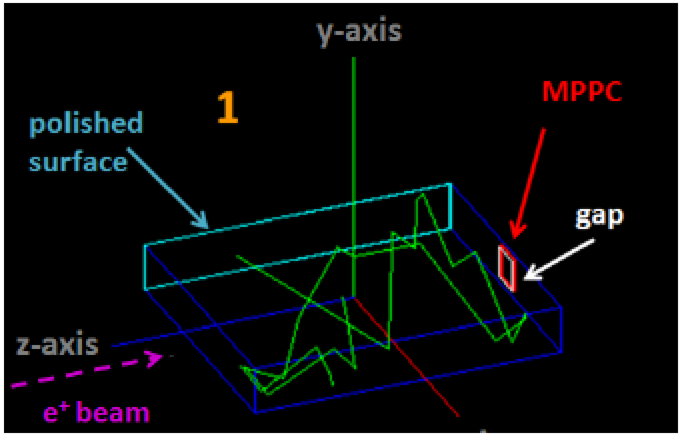
Material	Configuration	LY_{max} [p.e./MIP]	σ_{Cher} [p.e./MIP]
Sapphire	(1) Pos_{opp}	48±3	15±1
	→ (2) Pos_{lat}	29±2	9±1
	(3) rhombic *(rough)*	62±4	11±1
	(4) rhombic *(polished)*	53±3	12±1

* Temperature corrected at 20°C



Best uniformity of ~10% obtained with lateral readout of rectangular tile

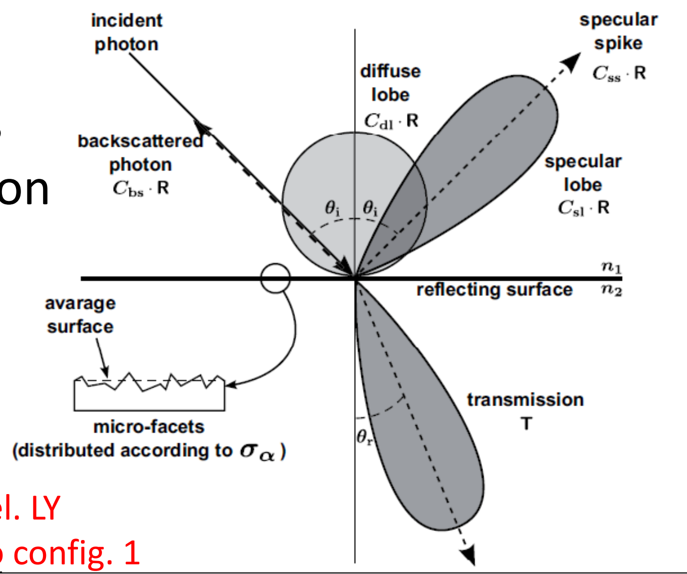
Attempt to simulate optical process



The art is in the surface definition

➔ Unified model

1 parameter defining the surface roughness and 4 types of reflection at the boundary



MC uncertainty from parameter scan:
16% (rough) and **12.4%** (polished)

- Absolute LY still off by about factor 3
- Relative behavior also not satisfactory
- Only uniformity in the same ball park

rel. LY to config. 1

Configuration	1	2	3	4
LY^{max}_{MC} [%]	100±16	112±18	148±24	63±8
LY^{max}_{DATA} [%]	100±6	60±4	129±8	110±6
$(\sigma/LY)_{MC}$ [%]	5.5±0.9	4.9±0.8	6.2±1.0	9.2±1.1
$(\sigma/LY)_{DATA}$ [%]	31.3±2.1	31.0±3.4	17.7±1.6	22.6±1.9
Non-uni.$_{MC}$ [%]	10.0±2	5±1	15±2	30±4
Non-uni.$_{DATA}$ [%]	17.0±2	3±2	22±2	30±2

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Conclusions / outlook

- Highly granular calorimeters for particle flow require single cell of typically few cm size
- Various solutions for scintillator tiles readout via SiPM exist

  ➔ need to optimize mass production for few millions

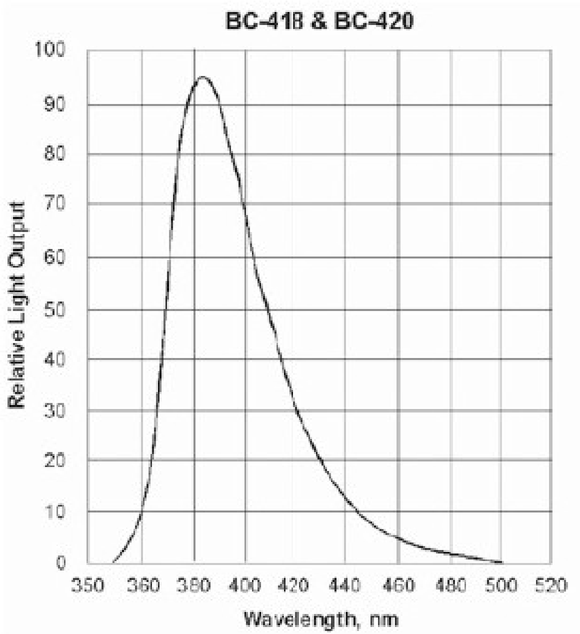
- Small Cherenkov emitting tiles (quartz or sapphire) can add dual readout capabilities to particle flow calorimeters
- The light yield obtained with a sapphire tile read out via MPPC is suitable for this application: **LY = (29 2) p.e./MIP**
- Tolerable non-uniformity of response with MPPC placed on the lateral side

- Attempted Monte-Carlo simulation (Geant 4.9.3) of optical photon not very successful ➔ more work needed

Next step: optimize the geometry of a dual readout particle flow calorimeter and test the improvement on energy resolution

BACKUP

- Active medium of choice: Plastic scintillator
  - Cheap, easy to machine, sensitive to charged particles and neutrons, ...



Typical emission spectrum of plastic scintillator:

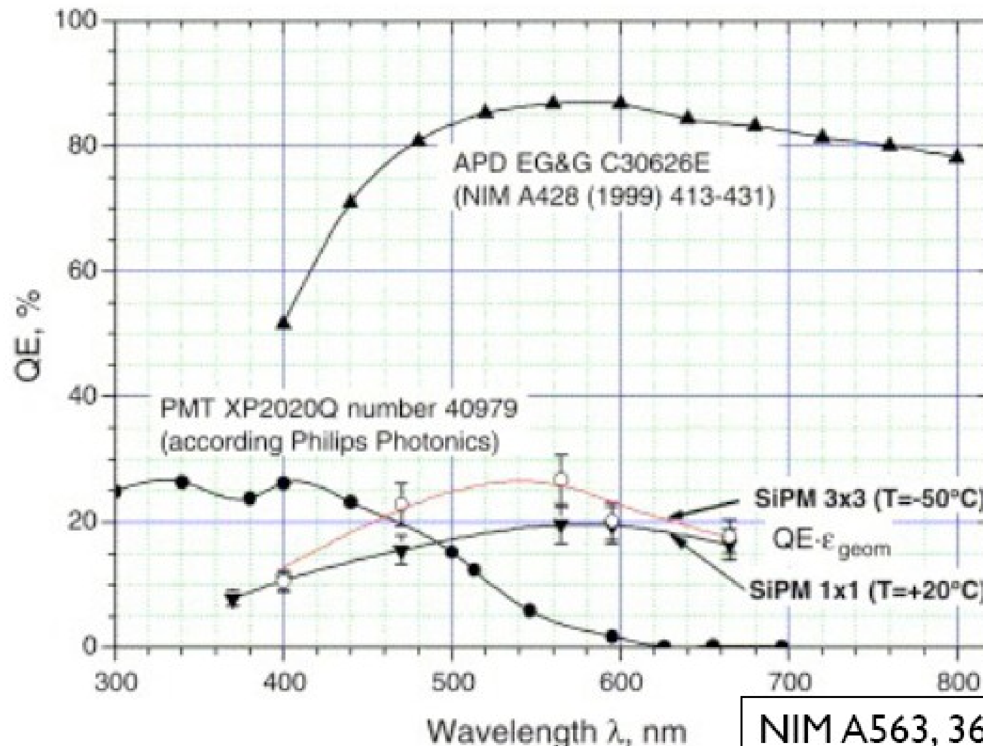
Maximum in the violet / blue spectral region 400 nm - 450 nm

First generation SiPMs:

Sensitivity maximum

~ 550 nm (green)

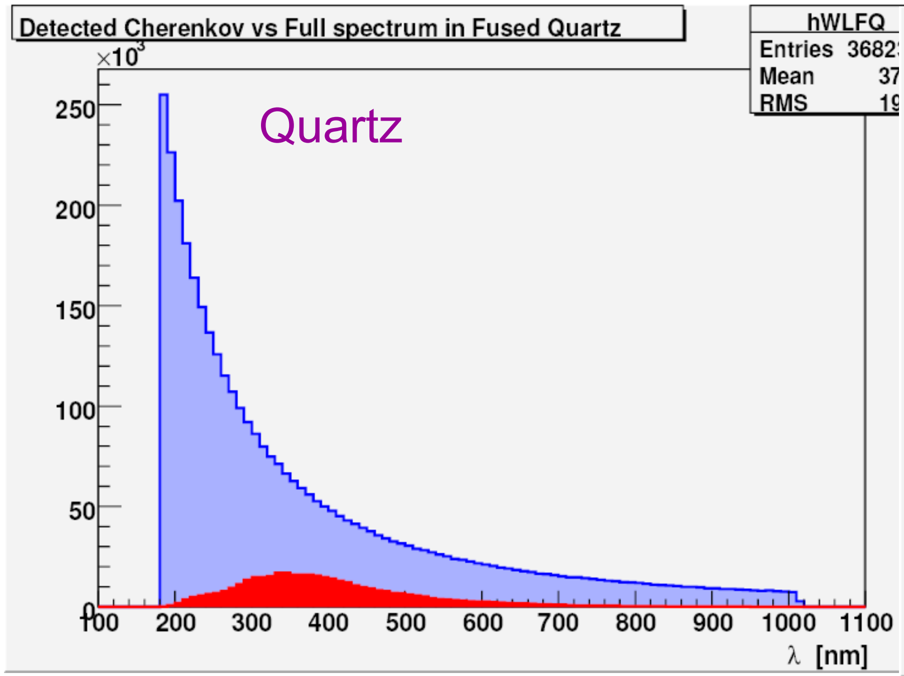
⇨ Wavelength-shifter needed!

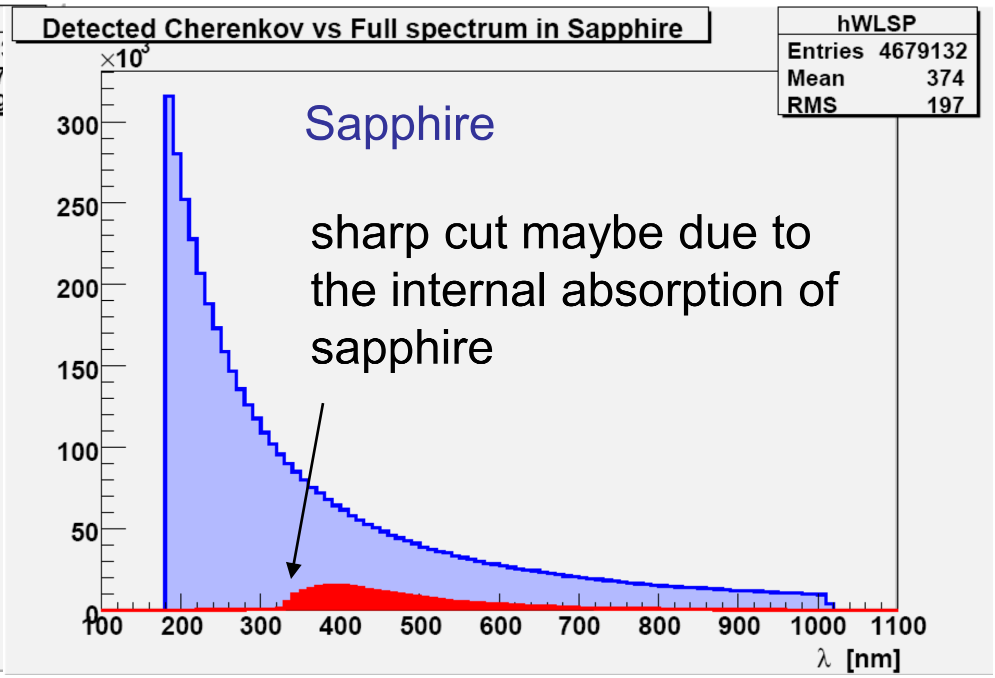


NIM A563, 368 (2006)

Cherenkov Spectrum and Quantum efficiency

The spectrum of generated Cherenkov light (blue) decreases as $1/\lambda$
The detected spectrum (red) is convoluted with the MPPC PDE

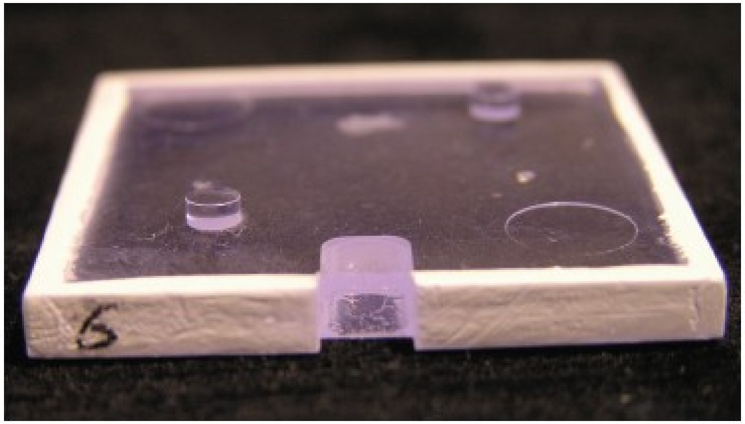


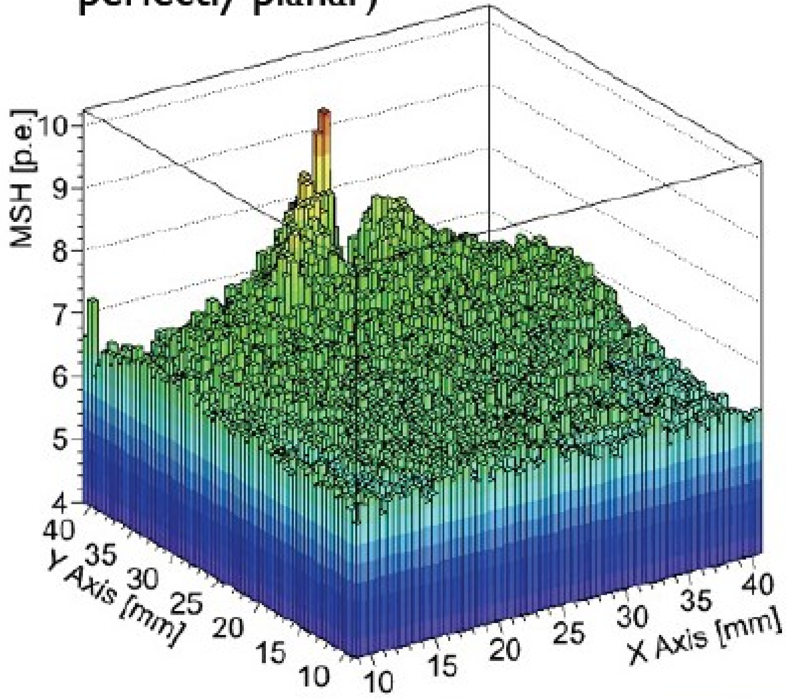


The ideal detector fore this application is a more UV sensitive one
➔ subject of further optimization

Variation on SiPM + scintillator tiles

- 3 mm thick tiles for 2nd generation
- Molded tile, produced by Uniplast (Vladimir, Russia), dimple was machined after molding
  - sides chemically matted, top and bottom enclosed in 3M foil, imperfect covering (tile not perfectly planar)





- Good uniformity
- Low signal amplitude: mean 6.8 p.e.
- Large signal spike close to SiPM: Potentially a coupling problem